PB82-205956

Monitoring Water Filters for Asbestos Removal

(U.S.) Municipal Environmental Research Lab.
Cincinnati, OH

1981

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-600/J-80-167
Journal Article

VOL.107 NO.EE6. DEC. 1981

JOURNAL OF THE ENVIRONMENTAL ENGINEERING DIVISION

PROCEEDINGS OF
THE AMERICAN SOCIETY
OF CIVIL ENGINEERS

NTIS is authorized to reproduce and sell this report. Permission for furthur reproduction must be obtained from the copyright owner.

Copyright© 1981 by
American Society
of Civil Engineers
All Rights Reserved
ISSN 0090-3914

Otis J. Sproul, Editor
Ohio State University

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before comp

1. REPORT NO. EPA-600/J-80-167	2. Journal Article	PB82-205956
4. TITLE AND SUBTITLE Monitoring Water Rilters for Asbestos Removal		5. REPORT DATE May 1982
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Logsdon, Gary S., Symons, James M., and Sorg, T. J.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Environmental Protection Agency Municipal Environmental Research Lab., Drinking Water Research Div., 26 W. St. Clair, Cincinnati, Ohio 45268		10. PROGRAM ELEMENT NO. BNC1A
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory - Cin.,OH Office of Research and Development U. S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
This was published in Journal of the Environmental Engineering Division, ASCE, Vol. 107, No. EE6, Dec. 1981, pp. 1297 - 1315.

16. ABSTRACT Water filtration processes can reduce the asbestos fiber count in drinking water by 90 to 99.9 percent, or more. Effective fiber removal requires very close control of the treatment process. Monitoring of filtered water turbidity can indicate the efficacy of treatment, even though the asbestos fiber concentration is too low to register as turbidity. Turbidity monitoring works because when water is properly prepared for filtration, passage of asbestos fibers through the filter is indicated by the passage of floc, as shown by higher turbidity. Filtered water turbidity should be 0.10 ntu or below for best fiber removal. Continuous monitoring of each filter module at a treatment plant is recommended. These findings are based on studies at Duluth, Two Harbors, and Silver Bay on Lake Superior; Seattle's Tolt reservoir, and on data obtained from the San Francisco Bay area.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Asbestos Filtration Monitoring Water Purification	Amphiboles Diatomaceous earth Granular Media Turbidity Water Treatment	13 B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 13
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

REPRODUCED BY
NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

6. Gilat C., Shuval, H. I., Yoshpe-Purer, Y., and Cohen, N., "The Use of Radioisotope Tracers in the Study of Dispersion and Inactivation of Bacteria Discharged in Coastal Waters," Proceedings of the 1970 Jerusalem International Conference on Water Quality and Pollution Research, presented at Ann Arbor-Humphrey Science Publishers, London, England, pp. 269–287.
7. Gilat C., Blit, S., and Meltzer, M., "Dispersion of Sewage and Disappearance Rate of Enteric Organisms from a Marine Outfall," Israel Atomic Energy Commission, 1973, 77 p.
8. Goldberg, M. B., and Chu, V., "Buoyant Forced Plumes in Cross Flow," *Journal of the Hydraulics Division*, ASCE, Vol. 100, No. HY9, Proc. Paper 10805, Sept., 1974, pp. 1203–1214.
9. Hirst, E., Buoyant Jets with Three Dimensional Trajectories, *Journal of the Hydraulics Division*, ASCE, Vol. 98, No. HY11, Proc. Paper 9378, Nov., 1972, pp. 1999–2011.

Monitoring Water Filters for Asbestos Removal

By Gary S. Logsdon,[1] M. ASCE, James M. Symons,[2] M. ASCE, and Thomas J. Sorg[3]

Introduction

Inhaled asbestos fibers are acknowledged as significantly increasing the risk of lung cancer and pleural mesothelioma, especially among smokers. When Canadian studies reported that asbestos fibers had been found in drinking water in 1971 (6), public health officials were concerned about the possible health hazards of ingesting asbestos fibers. Although unequivocal answers concerning health effects of ingested asbestos (amphibole and chrysotile) were not available in the early 1970's, and still are not available, those concerned with the safety of public water supplies generally have recommended minimizing exposure to ingested asbestos. This paper presents information on water quality monitoring that will be useful to water utilities that are attempting to minimize the concentration of asbestos in filtered drinking water.

Since the discovery of asbestos fibers in Lake Superior in 1973, water filtration plants have been built or modified for amphibole removal at Duluth, Two Harbors, Silver Bay, and Beaver Bay, Minnesota. In the mid-1970's asbestos fibers, predominately chrysotile, were also found in a number of water sources in the Cascade Mountains in Washington. A filtration plant has been designed for Everett, a community that has used unfiltered mountain water as its drinking water for many years. While the Everett pilot plant study (17) was under way, a very extensive program of pilot plant research for asbestos fiber removal (9,10) was being carried out on the Seattle Water Department's Tolt River watershed.

In the late 1970's, research at the University of California showed that asbestos was sometimes present in certain raw waters in the San Francisco Bay area (8). Asbestos fibers have been found in the raw water sources of a number

[1]Research San. Engr., Physical and Chemical Contaminant Removal Branch, Drinking Water Research Div., U.S. Environmental Protection Agency, Cincinnati, Ohio.
[2]Chf., Physical and Chemical Contaminant Removal Branch, DWRD, U.S. Environmental Protection Agency, Cincinnati, Ohio.
[3]Chf., Inorganic and Particulate Control Section, P&CCRB, DWRD, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Note.—Discussion open until May 1, 1982. To extend the closing date one month, a written request must be filed with the Manager of Technical and Professional Publications, ASCE. Manuscript was submitted for review for possible publication on December 19, 1980. This paper is part of the Journal of the Environmental Engineering Division, Proceedings of the American Society of Civil Engineers. ASCE, Vol. 107, No. EE6, December, 1981. ISSN 0090-3914/81/0006-1297/$01.00.

of other cities, including Philadelphia (12) and, in small amounts, Chicago (12).

The first major problem involving asbestos in drinking water in the United States centered on the Lake Superior area. Amphibole fibers were found in drinking water at Duluth and other north shore communities in Minnesota. In a very significant legal case involving pollution control (16), the fibers were shown to have originated at a Taconite processing plant at Silver Bay, Minnesota. Before the discharge of ore tailings to Lake Superior was halted in 1980, about 67,000 tons (61,000 metric tons) per day of the tailings were discharged to Lake Superior. As a result of this discharge, amphibole fiber counts along the western shore near Duluth generally ranged from 10×10^6 f/L (fibers/liter) to 100×10^6 f/L, and exceeded $1{,}000 \times 10^6$ f/L during severe storms on Lake Superior.

In the fall of 1973, plans for a pilot plant study were being discussed with engineers from EPA, the Corps of Engineers, and the Duluth Department of Water and Gas. On the basis of the very limited pilot plant work conducted by EPA in the summer of 1973, as well as earlier studies on removal of viruses (also very small particles) by filtration, engineering opinion held that granular media filtration ought to remove asbestos fibers. A key question related to monitoring and quality control. If the very slow and costly electron microscope counting of fibers was the only way to detect them with certainty, by what means could filtration plant operators control the treatment plant and be assured that the process was effectively removing fibers? This paper is intended to answer that question.

Monitoring Methods

A number of techniques for monitoring the fiber content of filtered water have been considered and tried in filtration research programs at Duluth, or Seattle or both, and are described briefly in this part of the report.

Electron Microscope.—The only method of analysis that provides positive identification of asbestos fibers is the transmission electron microscope (TEM) method. A method for counting asbestos fibers in water has been proposed by EPA (2). Electron microscopy is both slow and expensive. Sample analysis generally takes more than one working day, including all preparation steps, although analysis of a single sample usually does not require more than eight hours of an analyst's time. Asbestos analysis by TEM generally costs $300 or more per sample.

Because of the work load, most electron microscope laboratories (in 1980) are not able to provide results in less than three or four weeks after receipt of samples. Thus, electron microscope results cannot be used to monitor ongoing plant performance. They are very valuable, however, for reviewing past plant performance to decide if the treatment practice was effective for fiber removal.

X-Ray Diffraction.—The measurements of amphibole mineral in Duluth's drinking water in 1973 were made by X-ray diffraction (5). The method is quicker than TEM analysis and costs about one-fifth to one-tenth of the electron microscope method. Amphibole mass measurements were used during the Duluth pilot plant study and have continued to be used by the EPA laboratory in Duluth.

One disadvantage of amphibole mass measurement by X-ray diffraction is that the technique measures the mass of material and not the number of fibers. The presence of some very large pieces of amphibole could greatly increase the mass detected by the technique without increasing significantly the number of fibers.

X-ray diffraction has not been used to determine the mass of chrysotile in any water supply with chrysotile contamination. Work has been done on the measurement of chrysotile by X-ray diffraction, but many technical problems must be resolved before this could provide a less expensive method for detection of chrysotile in drinking water.

Particle Counters.—A limited amount of work has been done with HIAC particle counters (Pacific Scientific, Montclair, Ca. Mention of trade names or commercial products does not constitute endorsement or recommendation for use) in efforts to learn if numbers of larger particles (cross-sectional area equal to that of a sphere of 1.0 μm or 2.5 μm or larger) correlate with numbers of asbestos fibers. Results are limited and inconclusive and sample contamination may exist. Results from Seattle, Everett, and Duluth suggest that an in-line system with the filtered water piped directly to the counter would minimize contamination and offer the best prospects for successful application of this device.

Laser-Illuminated Optical Detector.—Under a research grant from the U.S. Environmental Protection Agency, a laser-illuminated optical particle detector was developed at the University of Minnesota-Duluth. This device was described in an EPA report (7). A multiple detector system uses differences in the scattering signatures of different types of particulates to identify the particulates. This detector was used to study red clay, taconite tailings, amphibole fibers, and chrysotile fibers. Detector output was related to electron microscope counting data so that the instrument could be used to estimate the concentration of fibers in water. Fiber levels as low as 0.05×10^6 f/L could be detected. An important advantage of the detector was that results could be obtained in a matter of minutes. Even when fiber counts are very low (under 0.01×10^6 f/L), results should be available in less than 1 hr. This instrument provides a rapid estimate of the number of fibers in water and is capable of identifying the types of particles present, if the water does not contain particles that were absent when the calibration was done.

Turbidity Measurement.—Of the methods described, turbidity measurement has perhaps the most disadvantages. Turbidimetry is not specific for asbestos fibers and cannot differentiate between light scattered by fibers, or clay, or diatoms, or any other particulates. Lawrence's data on measurement of asbestos fibers show that fiber counts below 10^{10} f/L are not readily detected by a turbidimeter (11). Asbestos fibers in concentrations found in most raw waters and nearly all filtered waters are too low to cause a turbidimeter to register any light scatter. A turbidimeter alone cannot be used to detect and quantify asbestos fibers in drinking water.

Turbidity and asbestos fiber counts in *unfiltered* waters may correlate weakly or very poorly. A weak relationship existed for Seattle raw water chrysotile or amphibole and turbidity (9). Little or no relationship was observed for amphibole fiber counts and raw water turbidity in the Duluth pilot plant study. Fig. 1, a typical figure, shows why trying to associate a fiber count with a given turbidity value often would not give a satisfactory estimate of the asbestos concentration.

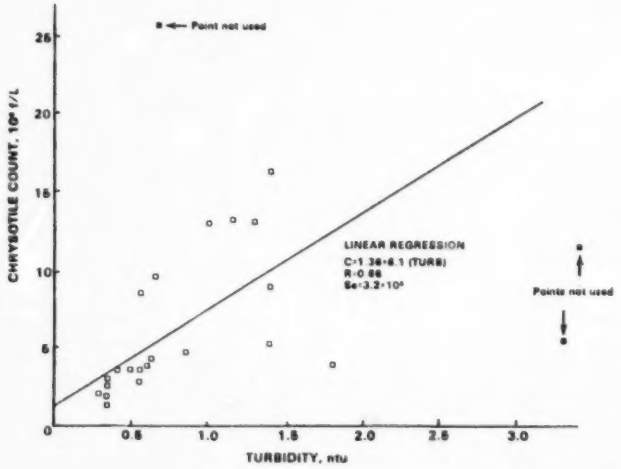

FIG. 1.—Raw Water Chrysotile versus Turbidity, Seattle Pilot Plant

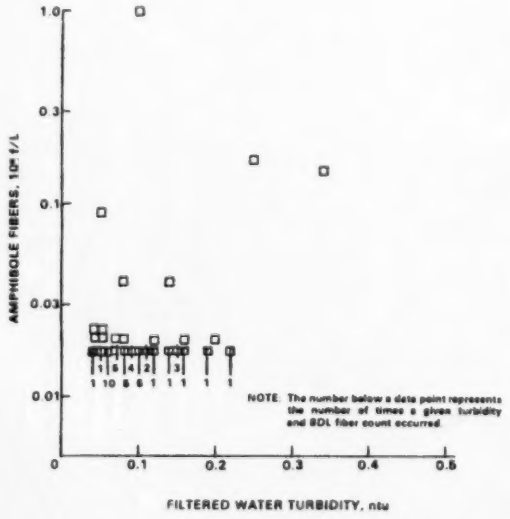
AMPHIBOLE FIBERS, 10⁶ f/L
NOTE: The number below a data point represents the number of times a given turbidity and BDL fiber count occurred.
FILTERED WATER TURBIDITY, ntu

FIG. 2.—Effluent Turbidity versus Amphibole Fiber Count, Duluth Granular Media Pilot Plants

TURBIDITY AS INDICATOR OF WATER QUALITY

Even though turbidity measurements do not correlate well with fiber counts in unfiltered waters, turbidity measurements are useful as an indicator of the quality of water being produced by a filter.

Turbidity versus Fiber Count.—The Duluth pilot plant work showed that amphibole fiber counts were likely to be at or near the detection limit when filtered water turbidity was below 0.2 nephelometric turbidity units (ntu). In Fig. 2, of the 41 BDL (below detectable limit) counts reported, 31 occurred when filtered water turbidity was 0.10 ntu or lower. Logsdon and Symons (14) recommended that quality control for filter operation at Duluth should be based on producing finished water with a turbidity of not more than 0.10 ntu, with

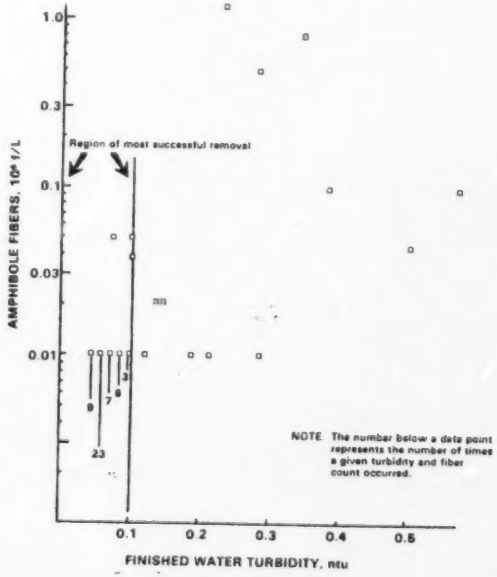
Region of most successful removal
AMPHIBOLE FIBERS, 10⁶ f/L
NOTE: The number below a data point represents the number of times a given turbidity and fiber count occurred.
FINISHED WATER TURBIDITY, ntu

FIG. 3.—Amphibole Count versus Finished Water Turbidity, Seattle Pilot Plant

the run being terminated when the turbidity reached 0.2 ntu. The significance of the trailing zero in the 0.10 ntu value will be analyzed later in the paper.

Review of the Seattle data indicates that amphibole fibers can consistently be removed down to the detection limit of 0.01×10^6 fibers/L. When amphiboles were detected in the raw water and when filtered water turbidity was equal to or less than 0.10 ntu, 52 out of 57 results (91%) had levels of amphibole which were at or less than the detection limit. As indicated in Fig. 3, when the finished water turbidities exceed 0.10 ntu, amphibole counts are much higher and the data show a noticeable scatter (9). These data points represent times when either poor destablization was occurring or when turbidity breakthrough had already taken place.

The Seattle chrysotile data (9) indicate that although excellent removals can be achieved, chrysotile is more difficult to remove than amphibole and results are more variable. Fig. 4 shows a very tight pattern of data when finished water turbidity is equal to or less than 0.10 ntu and considerable scatter above that point. As with the amphibole results, the scattered chrysotile data above 0.10 ntu are normally associated with either poor destablization, turbidity spikes, or breakthrough. Both Figs. 3 and 4 are very similar to results obtained in the Duluth pilot plant study.

Turbidity and Probability of High Fiber Counts.—Filtered water turbidity of monitoring samples at the Lakewood filtration plant was routinely 0.04–0.06

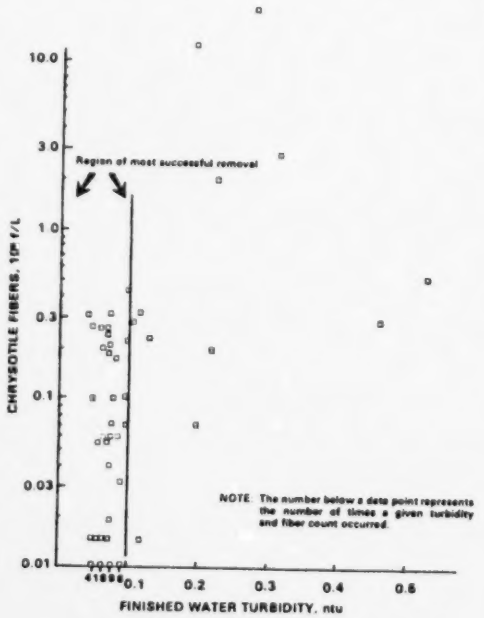

FIG. 4.—Chrysotile Count versus Finished Water Turbidity, Seattle Pilot Plant

ntu. The lower turbidity values approached the detection limit for the nephelometer employed, and asbestos results were frequently at or near the detection limit too. A direct comparison of filtered water turbidity versus fiber count would not be very useful, so another approach was taken (13). Filtered water fiber count data from Duluth were grouped according to turbidity and operating conditions. Differences in the fiber counts for the data groups are apparent in Fig. 5, which shows the probability of occurrence of fiber counts for the various operating conditions.

In Figs. 5 and 6, when a BDL fiber count was reported, the data point was plotted at the detection limit. This resulted in clusters of data points at certain fiber count values, and is a conservative approach to data analysis because

actual fiber counts could have been below the BDL values.

Fig. 5 clearly shows that lower fiber counts are more likely to occur when the turbidity of filtered water is 0.10 ntu or lower. In this turbidity range, amphibole fiber counts were 0.03×10^6 or less during half the time of normal plant operating conditions.

Kirmeyer (9) showed a similar trend with Seattle chrysotile data. Fig. 6 can be used to estimate what levels of chrysotile were present at any given time when finished water turbidity was ≤0.10 ntu or above 0.10 ntu. For example,

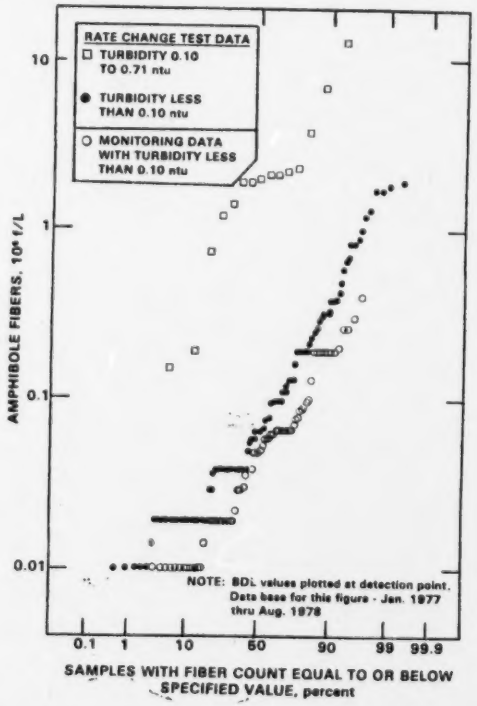

FIG. 5.—Comparison of Frequency Distributions of Fiber Counts of Filtered Water Sample Groups, Lakewood Plant, Duluth

50% of the time when turbidity was ≤0.10 ntu, finished water chrysotile counts were $\leq 0.03 \times 10^6$ fibers/L. When turbidity was >0.10 ntu, 50% of the time, chrysotile counts were $\leq 0.3 \times 10^6$ fibers/L. Thus, over 10 times more asbestos was present in the finished water when turbidity was >0.10 ntu as compared to when turbidity was ≤0.10 ntu.

Turbidity as Indicator of Filter Performance

Individual Filter Run Data.—Kirmeyer showed that turbidity measurements

could be used as an indicator to determine whether or not a granular media filter was removing asbestos fibers (9). In a number of filter runs for which several asbestos analyses are available, filtered water turbidity and fiber count data show similar trends, with both turbidity and fiber counts increasing, decreasing, or remaining constant during portions of a filter run. Results from three runs (9) are presented in Figs. 7–9.

Filter run 21 was conducted using 7 mg/L of alum, with lime for pH control and a polymer as a filter aid. Results are shown in Fig. 7. The results indicate that when finished water turbidity was ≤0.10 ntu, then chrysotile counts were

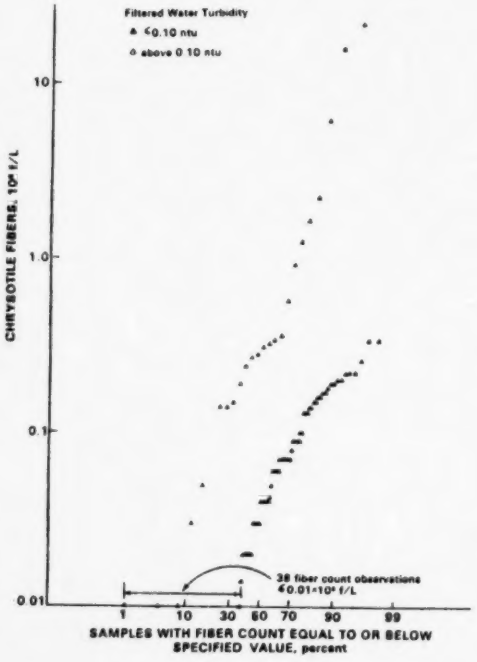

FIG. 6.—Frequency Distribution of Chrysotile Fiber Counts for Filtered Water Sample Groups, Seattle Pilot Plant

0.34×10^6 f/L or less. At hour 7 of run #21, the finished water turbidity spiked at 0.34 ntu when the pH of the coagulated water unintentionally rose to a value too high for proper floc formation. At this time, the finished water chrysotile rose from NSS (not statistically significant, less than 5 fibers in 20 fields) levels up to 12.25×10^6 fibers/liter.

A test of declining rate filtration, run 174, was conducted using 10 mg/L of alum, lime for pH control, and a nonionic polymer as a filter aid. Initial filter loading rates were as high as 10 gpm/sq ft (24 m/hr). To test the sensitivity of the turbidimeter in detecting changes in the operation of the filter, the alum

feed pump was temporarily shut off after the first hour of operation and finished water turbidity was monitored continuously during the process. Within about 15 min after the pump was turned off, the finished water turbidity began to rise rapidly. The detention time between the rapid mixer and the filter bed can be estimated at about 13.5 min. A comparison of these two times, 15 versus 13.5 min, indicates that the simple turbidimeter functions exceptionally

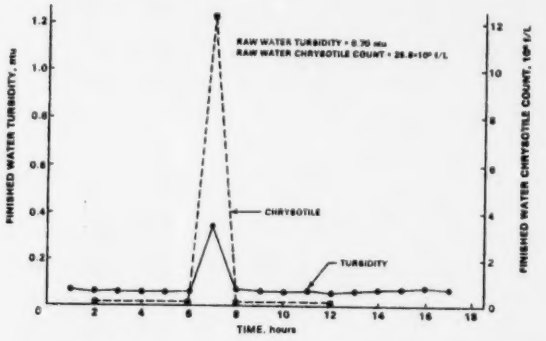

FIG. 7.—Finished Water Turbidity and Chrysotile versus Time-Run #21, Seattle Pilot Plant

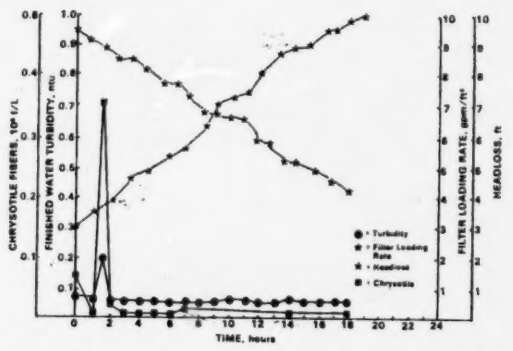

FIG. 8.—Operating Data for Run #174MM, Seattle Pilot Plant

well as a "troubleshooting" instrument and could have alerted an operator that something was wrong somewhere in the system. Within 15 min after the alum pump was placed back into operation, the finished water turbidity returned to ≤0.10 ntu and stayed at that low level for the duration of the filter run. Asbestos analyses conducted before, during, and after pump shutdown are presented in Fig. 8. These data indicate that when the alum pump was off and finished water turbidity had risen only to 0.20 ntu, a noticeable increase in chrysotile counts occurred, as compared to the very low levels previously measured.

Fig. 9 provides an excellent example of how finished water turbidity and asbestos counts track during filter breakthrough. This filter run indicates that high chrysotile counts in the filtered water coincide with filter breakthrough as indicated by a rising finished water turbidity.

Interpretation of Summarized Performance Data.—To test the relationship of fiber removal and filtered water turbidity at Seattle, a statistical analysis was performed using Seattle data. Fiber removal percentages were calculated, and data were placed into four fiber removal categories: >99.0%, >95.0–99.0%, >90.0–95.0%, and 90.0% or less. Then the number of each of these samples with filtered water turbidity above 0.10 ntu, and 0.10 ntu or less, were placed in Table 1. This was done separately for amphibole and chrysotile results. The

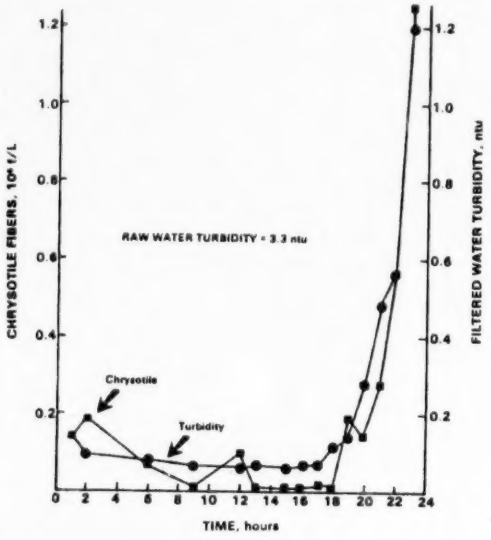

FIG. 9.—Finished Water Chrysotile Counts and Turbidity versus Time-Run #120, Seattle Pilot Plant

hypothesis in each case was that no difference existed in the frequency of observation of the various fiber removal percentages for the sets of data grouped according to filtered water turbidity. The results were statistically different from the expected (null hypothesis) at the 0.01 level for both amphibole and chrysotile. Thus the Seattle results also showed that the degree of fiber removal attained is related to filtered water turbidity.

In another test of the relationship of fiber removal and turbidity, fiber removal data for chrysotile were placed into the four percentage categories used in the chi square analysis. Then data for each category were arranged in order according to filtered water turbidity. The results were plotted on logarithmic probability paper, showing the percentage of samples of a given fiber removal having turbidity equal to or less than a certain value. Results are presented

in Fig. 10 and clearly show that higher filtered water turbidities are associated with lower percentages of chrysotile removal.

An example of how the results in Fig. 10 could be used follows. If, on the basis of raw water data, the water department chose to operate a filtration plant to attain at least 99% reduction in the fiber count, producing water with a filtered turbidity of 0.10 ntu or less would be necessary 95% of the time. Filtered water turbidity, over a long period of time, could be allowed to exceed

TABLE 1.—CHI Square Analysis of Fiber Removal and Turbidity—Seattle

Turbidity of filtered water (1)	Number of Samples with Fiber Removal Percentage			
	>99.0% (2)	>95.0–99.0% (3)	>90.0–95.0% (4)	≤90.0% (5)
		chrysotile data		
≤0.10 ntu	48	43	7	3
>0.10 ntu	2	7	6	9
		$X^2 = 38.5$		
		amphibole data		
≤0.10 ntu	6	9	0	0
>0.10 ntu	0	0	1	2
		$X^2 = 18.0$		

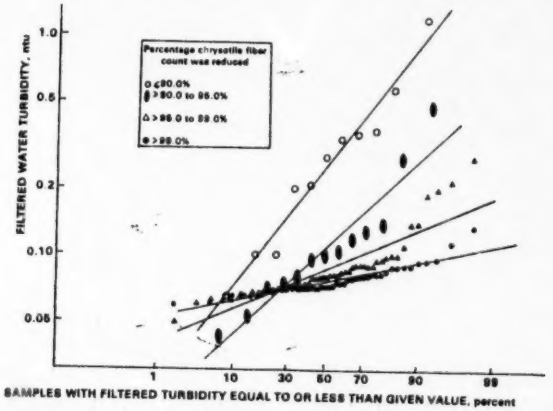
FILTERED WATER TURBIDITY, ntu
Percentage chrysotile fiber count was reduced
SAMPLES WITH FILTERED TURBIDITY EQUAL TO OR LESS THAN GIVEN VALUE, percent

FIG. 10.—Relationship of Turbidity and Chrysotile Removal by Granular Media Filtration, Seattle Pilot Plant

0.10 ntu only 5% of the time in order to consistently attain 99% fiber reduction. On the other hand, if only a 90% reduction of chrysotile was needed, turbidity would have to remain below 0.35 ntu 95% of the time. If chrysotile removal was of no consequence, and less than 90% removal was acceptable, meeting the 1 ntu limit of the Drinking Water Regulations (15) could be an operating goal.

Diatomite Filtration for Asbestos Fiber Removal

At Duluth, amphibole fibers were effectively removed by diatomaceous earth (DE) filtration. In their reviews of the Duluth pilot plant study, both Baumann (3) and Logsdon and Symons (14) cited the use of alum-coated diatomite as particularly effective. Baumann suggested that alum-coated filter media would have a positive surface potential, and that amphibole particles in the pH range of 7–8 (Lake Superior raw water pH) would be negatively charged. This charge difference would enhance the attraction of amphiboles to the diatomite filter aid particles. Surface attachment could occur, facilitating the removal of amphibole fibers too small to be removed by straining.

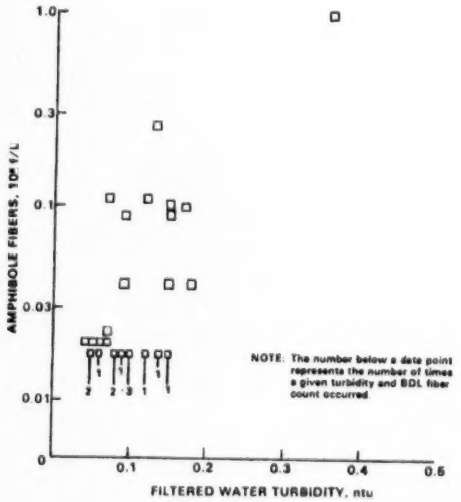

FIG. 11.—Effluent Turbidity versus Amphibole Fiber Count for Pressure Diatomite Filtration, Duluth Pilot Plant

The use of both pressure and vacuum diatomite filters at Duluth permitted comparison of the two kinds of equipment. Pressure filtration was more effective than vacuum filtration for removing amphiboles and turbidity-causing particulates. This may have been the result of raw water quality and a fundamental difference in the two types of filters. The pressure filter pump was on the influent side of the filter. It provided a positive pressure, or driving force through the filter, of up to 100 ft (30 m) of water, as observed in head-loss measurements in some early long filter runs. Water passed through the pressure filter and was discharged at atmospheric pressure.

In the vacuum filter operation, the driving force was the difference between atmospheric pressure at the influent side of the filter, and the suction at the pump on the effluent side of the filter. Head loss for the vacuum filter runs was less than 15 ft (4.6 m) of water in most runs.

When the clear, cold, oxygen-saturated water from Lake Superior passed through the vacuum filter and pressure dropped below 1 atm, the dissolved gases tended to come out of solution and form bubbles in the filter cake. These bubbles could grow and collapse, permitting solids to bleed through the filter cake. From June 21–August 27, according to pilot plant operators' notes, bubbles were observed on the vacuum filter septum in 18 out of 67 runs. Because of the air bubble problem associated with filtering very cold waters, pressure filtration is better suited to such situations.

During the last half of the Duluth pilot plant study, pressure DE filtration repeatedly produced water with turbidity of 0.10 ntu or lower. For amphibole removal, the use of pressure filtration with alum-coated diatomaceous earth would be recommended. The grade of diatomite selected should be fine enough to produce a filtered water of 0.10 ntu or lower, because high fiber counts were usually associated with turbidities above 0.10 ntu (Fig. 11). Nine of twelve BDL counts occurred with turbidities of 0.10 ntu or lower.

If the septum pores are too large to permit effective precoating with the fine diatomite, a two-stage precoating process could be used, with the coarser DE coated on the septum, and then a second layer of fine DE placed over the first precoat layer. Only the second layer of precoat in such a case would need to be alum-coated. Two-stage precoat was used often at Duluth.

The data obtained at Duluth show that DE filtration is effective for amphibole removal. The number of comments and recommendations that can be made regarding DE filtration for asbestos fiber removal is limited, however, because no extensive pilot plant research has been carried out since 1974, and no monitoring data are available.

Analysis

Turbidity measurement can be used as a guide to filter operation for asbestos fiber removal if the limitations of this technique are considered. This portion of the paper presents some advantages and disadvantages of turbidity measurement and sets forth a proposed goal for turbidity of filtered water when asbestos fiber removal is desired.

Turbidity-Fiber Count Relationship in Filtered Water.—The nature of the turbidity-fiber relationship for filtered water could perhaps be compared to the coliform-pathogen relationship. The presence of coliforms is a signal that pathogens might be present. It is, however, not certain proof of pathogen presence and no direct proportional ratio for the two kinds of microorganisms exists. Similarly, when raw water contains asbestos fibers, a rise in filtered water turbidity is probably a sign of an increase in filtered water fiber count, but the fiber count cannot be estimated on the basis of the abnormally high turbidity reading. Data from the Seattle study are presented in Table 2 to show this. One sample with 0.24 ntu turbidity had 11×10^6 f/L, whereas another with 0.28 ntu had a statistically insignificant count of about 0.14×10^6 f/L.

When a granular media filter has been operating for a period of time and has been producing a stable quality of effluent as measured by turbidity, a rise in filtered turbidity should be interpreted as a sign that some operator action is required. An adjustment of chemical doses or a filter backwash may be necessary. When a granular media filter is removing a contaminant in particulate

form, such as asbestos fibers, a rise in filtered water turbidity is a strong indication that the particles that had been captured within the filter are now being released.

Table 3 contains data on fiber counts from two Seattle pilot plant runs. In run 53, when the turbidity rose to 0.24 ntu after 9 hr of filter operation, the chrysotile count in the filtered water was nearly four times that in the raw water. In run 62, when turbidity rose to 0.37 ntu at 16 hr, chrysotile counts in raw and filtered water were quite similar. Amphibole data for run 62 show

TABLE 2.—Seattle Pilot Plant Chrysotile Fiber Counts in Filtered Water When Turbidity Rose Above 0.10 ntu

Run (1)	Hours into run (2)	Filtered turbidity ntu (3)	Fibers 10^6 fibers per liter (4)
21	7	0.34	12.25
24	7	0.36	6.2
53	9	0.24	11.2
62	16	0.37	2.28
120	1	0.14	0.14
120	19	0.14	0.19
120	20	0.28	0.14[a]
120	21	0.48	0.28
120	22	0.57	0.57
120	23	1.2	1.25

[a]Not statistically significant.

TABLE 3.—Release of Asbestos Fibers by Filters at Seattle Pilot Plant

Run (1)	Sample location (2)	Hour into run (3)	Turbidity ntu (4)	Chrysotile fibers per liter (5)	Amphibole fibers per liter (6)
53	Raw	9	0.50	3.0×10^6	0.70×10^6[a]
53	Finished	3	0.13	0.27×10^6	$<0.02 \times 10^6$ (BDL)[b]
53	Finished	9	0.24	11.2×10^6	1.2×10^6[a]
62	Raw	16	0.35	2.52×10^6	$<0.1 \times 10^6$ (BDL)[b]
62	Finished	3	0.1	0.34×10^6	$<0.02 \times 10^6$ (BDL)[b]
62	Finished	9	0.105	0.24×10^6	$<0.02 \times 10^6$ (BDL)[b]
62	Finished	16	0.37	2.28×10^6	0.1×10^6

[a]Not statistically significant.
[b]Below detectable limit.

that granular media filters can store and then slough particulate contaminants. Amphibole fibers were not detected in raw water or in filtered water during normal operation in this run, but when turbidity rose at hour 16, amphibole fibers that apparently had been removed and concentrated in the filter were released in a concentration high enough to be detected in the filtered water.

The sloughing and discharge of asbestos fibers from filters that previously had removed them from the raw water is a potential problem that filter plant operators must consider. Existing data suggest that the best way to prevent

the discharge of a concentrated amount of fibers into filtered water is to avoid any significant rises in turbidity after a granular media filter has ripened and effluent turbidity is stable.

The extent of a turbidity rise that could cause a problem is not well defined, but in run 53 an increase from 0.13–0.24 ntu resulted in a forty-fold increase in the chrysotile count. For a filter producing 0.10 ntu filtered water, a rise of 0.1 ntu is probably sufficient cause to backwash the filter. Controlling the operation of a filter in this manner is being accomplished at some filtration plants, but for many others it would represent a considerable modification of operating procedures.

Advantages and Problems of Monitoring Filters by Turbidimetry.—An advantage of turbidity is that this measurement has been performed by water utilities for many years. Water utility personnel are familiar with turbidimeters and experienced in their use. Another advantage is the low cost. Continuous turbidimeters with recorders can be obtained for as little as $1,000, or about the cost of three sample analyses by TEM. When continuous turbidimeters are used, changes in filtered water turbidity can be detected within a matter of minutes, enabling the plant operator to change chemical doses quickly and return the plant to normal operation.

Turbidity measurement has some important drawbacks that have to be recognized by plant operators, however. The most significant one is the inability of a turbidimeter to count asbestos particles. Under normal circumstances, a given turbidity reading cannot mathematically be related to a fiber count. Similar turbidity values may be related to drastically different fiber counts, as shown in Table 2. If fiber counting data are needed, electron microscope analysis has to be carried out, because a fiber count for a single sample cannot be calculated by use of turbidity data. Turbidity data could not be used to determine whether fibers are present or absent in unfiltered water.

Even though the turbidity-asbestos fiber content relationship in water does have serious limitations, continuous turbidity measurement is a very rapid and low cost method for observing trends in water quality. Controlling these trends is the proper approach for the use of turbidity measurements in filtration plants operated for asbestos fiber removal.

Goal for Filtered Water Turbidity.—If filtered water turbidity measurement is to be used as a means to control treatment plant operation, a water quality goal is needed. For removal of asbestos fibers, a goal of 0.10 ntu is suggested. This is considerably lower than the 1 ntu Maximum Contaminant Limit set forth in EPA's Interim Primary Drinking Water Regulations (15), but similar to the American Water Works Association's (AWWA) quality goal of 0.1 ntu (1). The AWWA goal technically can be met with a turbidity of 0.14 ntu because of rounding off to one significant figure beyond the decimal point. The 0.10 ntu value is based mainly upon analysis of data from the Duluth and Seattle pilot plant research projects, and the results obtained since 1977 at Duluth's filtration plant. These results show that fiber counts tend to be higher when filtered water turbidity exceeds 0.10 ntu, and lower when the turbidity is 0.10 ntu or below.

Problems with and limitations of the use of a turbidity value as a guide to operating filters for asbestos fiber removal should be clearly set forth. The data on which the 0.10 ntu value is based were obtained at filtration plants

treating water having low turbidity—generally 1 ntu and nearly always less than 5 ntu. Also, treatment involving coagulation must be done in a way that completely destabilizes the particulates in the water. The use of inadequate treatment chemicals can result in less than complete particle destabilization and may lower fiber removal efficiency.

Use of Adequate Treatment Chemical Dose.—A very important aspect of treatment process control is maintaining the proper doses of treatment chemicals. Polymers generally have a range of concentration that gives optimum efficacy, with reduced effectiveness resulting from either an overdose or an underdose of coagulant aid or filter aid. Inorganic coagulants must be used in doses adequate to assure that particulates are destablized before filtration.

When very clear water (close to 1 ntu) is filtered, meeting the 1 ntu Maximum Contaminant Limit for turbidity can sometimes be accomplished without the addition of coagulant chemical. Often 1 ntu filtered water can be produced with a very small coagulant dose, such as 2–5 mg/L alum. Producing very low turbidity filtered water, 0.10 ntu or below, requires higher doses of treatment chemical and more careful filter operation.

Available data (12) suggest that the turbidity-asbestos relationship holds only for waters treated with enough coagulant either to agglomerate particles, so they will settle, or to destabilize all or nearly all of the particles in the raw water so they will be removed in the filter. At one plant, when low coagulant doses or no coagulants were used, fiber counts were in the range of $1–2 \times 10^6$ f/L, even though filtered turbidities were 0.1–0.3 ntu (12). Kirmeyer (9) also reported that use of a low alum dose (6 mg/L) resulted in filtered water turbidity of 0.20 ntu but a chrysotile count of 1.6×10^6 f/L. Apparently, filtration plant operators trying to maximize asbestos fiber removal should not try to minimize application of coagulant chemical.

Influence of Source Water Turbidity on Treatment Results.—The source waters at Seattle and along the north shore of Lake Superior, where extensive filtration studies have been carried out, are very clear and generally unpolluted waters (except for the asbestos fiber content). Filtration of very clear water requires diligent operator attention if the treatment process is to attain maximum efficiency. Particles must be completely destabilized and low filtered water turbidity must be achieved to remove asbestos fibers.

When turbid raw water is treated, the presence of a large number of particulates in the water seems to aid the agglomeration of particles, and some water plant operators have observed that turbid waters may be easier to treat than clear waters.

The relationship between filtered water turbidity and fiber count may be different in waters that are more turbid than Lake Superior and the Tolt Reservoir. For example, in Contra Costa County, California, monitoring data from the Antioch and Pittsburg plants showed effluent turbidities between 0.1 and 0.4 ntu (12), while effluent turbidity at the Bollman Plant was 0.06 ntu or lower. Nevertheless, fiber counts in filtered water were similar for all three plants, below 0.3×10^6 f/L in 12 of 14 instances. Two of these samples were in the $0.7–0.8 \times 10^6$ f/L range, and six samples had BDL or NSS values. Raw water turbidities generally were between 20 and 40 ntu.

At the San Geronomo plant in Marin County in the Bay area (12), two samples had counts above 1×10^6 f/L. For the first sample, raw water turbidity was

5 ntu, filtered water turbidity ranged from 0.6–1.0 ntu on the day of sampling, and the fiber count was 2×10^6 f/L. For the second sample, raw water turbidity was 46 ntu, filtered water turbidity ranged from 0.3–0.6 ntu at the plant on the day of sampling, and the chrysotile count was 12×10^6 f/L.

The results from Contra Costa County and Marin County suggest that attaining a filtered water turbidity of 0.10 ntu or less is not as important when the raw water turbidity is very low, approx 1 ntu. Perhaps when raw water contains enough clays, algae, bacteria, and other particulates to raise the turbidity significantly above 1 ntu, the asbestos fibers become associated with the other particulates and are removed along with them.

Data suggest that asbestos fiber removal can be accomplished when filtered turbidity exceeds 0.10 ntu, if the raw water turbidity is greater than 1 ntu. Sufficient data to define "turbid" waters for which this is true have not been obtained, however, nor is the upper limit for filtered water turbidity that is associated with good fiber removal apparent. Limited data suggest that 0.4 ntu might be adequate, but 0.6 ntu might not.

Too little data and too much uncertainty exist now to suggest an operating goal other than 0.10 ntu. Treating to attain either the AWWA Quality Goal, or 0.10 ntu, would require careful operation and excellent equipment performance at plants treating turbid water. A distinct advantage of such an exacting quality goal is that to achieve it, fluctuations in filtered water quality would not be permitted. A rise in turbidity, caused by run-termininating breakthrough or by a coagulant feed malfunction, could be a signal for immediate corrective action by the plant operator. Preventing the production of higher turbidity water would prevent the sloughing of asbestos fibers from filters and would thus improve filtered water quality.

Practical Application

On the basis of results presented in this report, granular media filters can be operated to dependably remove asbestos fibers. The most important factor involved is properly conditioning the raw water before filtration so that a low effluent turbidity is produced. Alum and cationic polymers have usually been used for coagulation. Polymers often are used as filter aids. Control of coagulant dose, to assure thorough and complete particle destabilization, is essential, as is careful control of process pH. Filter rates from 2–10 gpm/sq ft (5–24 m/hr) have removed asbestos fibers, but abrupt rate changes must be avoided, particularly if floc is not strong and could pass through the filter as a result of a rate increase. An appropriate goal for filtered water turbidity is 0.10 ntu, a goal that is now being met at some water filtration plants. Asbestos fiber counts are likely to increase very substantially as filtered water turbidity rises, so increases in turbidity over 0.10 ntu should be interpreted as a signal for corrective action by filter plant operators. Because turbidity is only an *indicator* of the presence of particulates in water, attaining the lowest possible filtered water turbidity is perhaps the best way to assure that a filtration plant is operating at maximum effectiveness.

Diatomaceous earth filtration data also suggest that fiber counts are more likely to be low when filtered water turbidity is 0.10 ntu or lower. Careful selection of the DE filter septum material so that the diatomite does not bleed

through during the filter run, and use of a grade of diatomaceous earth fine enough to produce the desired filtered water turbidity, are two important factors for effective operation of DE filters for asbestos fiber removal.

Continuous monitoring of the effluent from each operating filter, whether granular media or DE, is essential if maximum filter efficacy is to be achieved. Because small filtered water turbidity increases are often accompanied by large increases in fiber count, turbidity changes must be detected quickly so that necessary operating changes can be carried out. If all filtered water is piped into a clearwell and the various effluents are blended before turbidity is measured, quality deterioration in a single filter may be overlooked because of the averaging effect of the clearwell. The use of a continuous turbidimeter for each filter enables the plant operator to closely monitor and control filter operation at the treatment plant, and careful operation of filters is the key to effective removal of asbestos fibers.

Conclusions

1. Analysis of water samples by transmission electron microscope is the only method that provides asbestos fiber counts, but this technique can not be used for control of treatment plant operation because of the long time delay between collection of samples and receipt of results.

2. Turbidimeters do not directly detect asbestiform fibers in the range of concentrations of interest for drinking water, $0.01–1{,}000 \times 10^6 f/L$; nevertheless, when water is properly conditioned for granular media filtration, changes of turbidity of the filtered water usually signal changes in the fiber concentration of filtered water.

3. Filtered water turbidity should be 0.10 ntu or lower to attain maximum filter efficacy for fiber removal for both granular media and diatomaceous earth filtration.

4. Water treatment plants that filter water for the purpose of removing asbestos fibers should continuously monitor the effluent turbidity from each filter.

5. A small increase in turbidity (0.1–0.2 ntu) may be associated with a very large increase in asbestos fiber count in filtered water. For this reason, plant operators should backwash filters long before the 1 ntu Maximum Contaminant Level for turbidity is reached during turbidity breakthrough.

6. At granular media filtration plants, careful control of chemical feed rates should be maintained to assure that proper coagulant dose and pH are maintained at all times in order to maximize fiber removal.

Appendix.—References

1. American Water Works Association Statement of Policy, "Quality Goals for Potable Water," *Journal of the American Water Works Association*, Vol. 60, Dec., 1968, pp. 1317–1322.
2. Anderson, C. H., and Long, J. M., "Interim Method for Determining Asbestos in Water," *EPA-600/4-80-005*, United States Environmental Protection Agency, Athens, Ga., 1980.
3. Baumann, E. R., "Diatomite Filters for Asbestiform Fiber Removal from Water," Presented at the 1975 American Water Works Association Annual Conference, Minneapolis, Minn. (Printed as Appendix I of EPA-670/2-75-050).
4. Black & Veatch, Consulting Engineers, "Direct Filtration of Lake Superior Water for Asbestiform Fiber Removal: Project Report and Appendices A through I," *EPA-670/2-75-050a* through *EPA-670/2-75-050g*, United States Environmental Protection Agency, Cincinnati, Ohio, 1975.
5. Cook, P. M., Glass, G. E., and Tucker, J. M., "Asbestiform Amphibole Minerals: Detection and Measurement of High Concentrations in Municipal Water Supplies," *Science*, Vol. 185, 1974, pp. 853–855.
6. Cunningham, H. M., and Pontefract, R., "Asbestos Fibers in Beverages and Drinking Water," *Nature*, Vol. 232, 1971, pp. 332–333.
7. Diehl, S. R., Smith, D. T., and Sydor, M., "Optical Detection of Fiber Particles in Water, *EPA-600/2-79-127*, United States Environmental Protection Agency, Cincinnati, Ohio, 1979.
8. Kanarek, M. S., "Asbestos in Drinking Water and Cancer Incidence," thesis presented to the University of California, at Berkeley, Calif., in 1978, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.
9. Kirmeyer, G. J., "Seattle Tolt Water Supply Mixed Asbestiform Removal Study," *EPA-600/2-79-125*, *EPA-600/2-79-126*, and *EPA-600/2-79-153*, United States Environmental Protection Agency, Cincinnati, Ohio, 1979.
10. Kirmeyer, G. J., Logsdon, G. S., Courchene, J. E., and Jones, R. R., "Removal of Naturally Occurring Asbestos Fibers from Seattle's Cascade Mountain Water Source," *Proceedings*, American Water Works Association, 1979 Annual Conference, Part 2, pp. 903–927.
11. Lawrence, J., and Zimmerman, H. W., "Asbestos in Water: Mining and Processing Effluent Treatment," *Journal of the Water Pollution Control Federation*, Vol. 49, Jan., 1977, pp. 156–160.
12. Logsdon, G. S., "Water Filtration for Asbestos Fiber Removal," *EPA-600/2-79-206*, United States Environmental Protection Agency, Cincinnati, Ohio, 1979.
13. Logsdon, G. S., Schleppenbach, F. X., and Zaudtke, T. M., "Filtration Works Out Asbestos Fibers," *Water & Sewage Works*, Vol. 126, Oct., 1979, pp. 44–46.
14. Logsdon, G. S., and Symons, J. M., "Removal of Asbestiform Fibers by Water Filtration," *Journal of the American Water Works Association*, Vol. 69, Sept., 1977, pp. 499–506.
15. "National Interim Primary Drinking Water Regulations," *EPA-570/9-76-003*, United States Environmental Protection Agency, Washington, D.C., 1976.
16. *United States of America, et al. v. Reserve Mining Co., et al.* (File No. 5-72, Civ. 19-D. Minn.)
17. Watkins, J., Jr., Ryder, R. A., and Persich, W. A., "Investigation of Turbidity, Asbestos Fibers, and Particle Counting Techniques as Indices of Water Treatability of a Cascade Mountain Water Source," *Proceedings*, American Water Works Association 1978 Annual Conference, Part 2, No. 33-3, pp. 1–38.